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Sustainability in hydropower development—A case study

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ABSTRACT

Hydropower development has significant impacts on the society and community economically, environmentally and socially. These impacts may go beyond the regional level, even across the nation. As one of the largest scale hydropower developments in the world, the Three Gorges Project has attracted attentions right from the conception stage. This paper adopted a case study approach to investigate the sustainable development practice in the Three Gorges Project. The case study shows that under the guidance of the State Council, the China Three Gorges Corporation has devoted to manage environmental, economic and social sustainability issues of the Three Gorges Project across various project stages (e.g. conception, design, construction and operation). The sustainability practice adopted in the Three Gorges Project generally follows the Hydropower Sustainability Assessment Protocol developed by the International Hydropower Association. As a result, the environmental auditing is satisfactory to the national standards and the project has achieved numerous social and economic benefits. However, resettlement, coordinated development and ecological impacts on the local ecosystem present significant challenges to future hydropower developments. This study highlighted a number of factors contributing towards better sustainability performance of hydropower developments in China, e.g. international collaboration, system approach, ongoing monitoring and strategic human resource management. The experiences gained from the Three Gorges Project have been applied into other hydropower developments in China. This study provides a useful reference to the sustainable energy development practice over the world.

Contents

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1. Introduction

Electricity is essential for day-to-day activities of human beings. According to the International Energy Agency, the electricity demand will grow at an annual rate of 2.5% by 2030 and the energy investment needs amount to $26 trillion in 2008–2030 [1]. The traditional fossil fuel has played an important role to generate power and electricity in the last century. However, the pollution associated with the coal-fired power plants is so serious that great efforts have been put forward to seek the alternative energy resources. Hydropower is a green energy source that contributes less Greenhouse Gas (GHG) emissions and produces less pollution during the operation stage [2,3]. Compared to other green energy resources and traditional fossil fuel, there are a number of advantages associated with hydropower [4–6]:

- The hydropower resources are widely available over the world.
- Very efficient energy conversion with the help of proven and advanced technology and experience collected in past century.
- Low operating cost and long life span.
- The fuel (water) is not subject to the fluctuation of market conditions.
- Provides the flexibility of electricity production and supply.
- Improves the living conditions of surrounding areas.

Other benefits of hydropower include: irrigation and flood control [7,8]. As a mature power generation technology, hydropower accounts for some 20% of power generation worldwide [9,10].

However, the environmental and social costs of hydropower developments, e.g. resettlement requirements, potential restriction to navigation, modification to local land use patterns, impacts on terrestrial and aquatic habitats, and sediment composition should not be overlooked [8,11].

The past decade witnesses the strong economic growth of China. Even through encountering the global financial crisis, China managed to maintain the GDP growth of 9%. The rapid economic development in China creates a huge demand for energy and electricity. In 2008, the total energy consumption reached 2.91 billion tons of standard coal equivalent. In the current energy composition, fossil fuels remain the dominant sources of primary energy, ranging from 88% to 92% [12].

In the past 50 years, the hydropower has achieved massive development in China. The annual increase rate of the installed capacity reached 11% during the period from 2003 to 2009. As shown in Fig. 1, the total installed capacity of hydropower reached 196.79 GW by the end of year 2009 [13,14]. According to the strategic energy development plan released by the Energy Bureau, the installed capacity of hydropower will reach 270 GW in 2020 [15]. This is reinforced in the Twelfth Five Year Plan of Renewable Energy Development recently released by the Energy Bureau that 61 million kW will be added to the installed capacity of hydropower in next five years with the total installed capacity reaching 290 GW in 2015 [16]. The authority considers an even more ambitious goal to 350 GW however the migration issue will be a significant barrier. Indeed, uneven precipitation distribution, lack of coordinated development, resettlement and impacts on local ecosystem present challenges to further hydropower developments in China [8,14,17].

The Three Gorges Project (TGP) was officially completed in 2009. As the largest scale hydropower development over the world, this completion signaled the state of art of the renewable energy development. This paper adopted a case study approach to investigate the sustainable development of this massive project and the sustainable development strategies employed by the

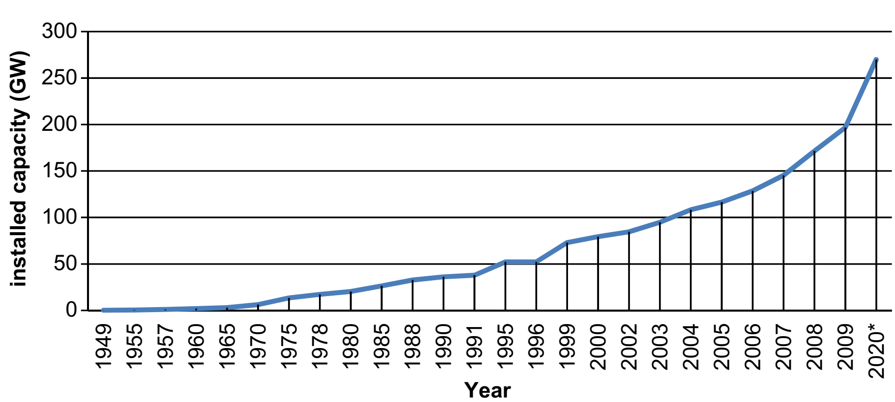

Fig. 1. Installed capacity of hydropower. * predicted value as per the Energy Authority.
Source: [13,14].

Table 1
Criteria of sustainability assessment of hydropower developments.
Source: [30,31].

Environmental	Social	Economical
Air and water quality	Reduce poverty and enhance the quality of life	Capital cost and recurrent cost
Waste management	Equitable distribution of the benefits of the project	Savings on GHG emissions and improved air quality
Sediment transport and erosion	Effectiveness and ongoing compensatory and benefits	Payback period
Downstream hydrology and environmental flows	Public health	
Rare endangered species	The impacts of displacement on individuals and communities	
Passage of fish species	Community acceptance	
Pest species within the reservoir (flora & fauna)	Protection of cultural heritage	
Health issues		
Impacts of construction activities on the terrestrial and aquatic environment		
Adoption of independently audited environmental management systems		

China Three Gorges Corporation. The lessons learnt can be applied to other renewable energy developments.

The research objectives of this study are: (1) to review sustainability issues associated with hydropower developments; (2) to investigate the sustainability practices adopted in the TGP; and (3) to discuss lessons learnt for future renewable energy developments.

2. Sustainable hydropower development—a literature review

Sustainability has become the focal point of nearly every single development. A number of studies offer definitions of sustainability and sustainable development with some slight variations. In essence, sustainability means that what we are doing is not at the expense of the future generation [18]. It is well recognized that sustainability is multi-facet concept. As a result, the triple bottom line approach has been commonly adopted to emphasize that developments need to be sustainable not only economically, but also socially and environmentally. Ribeiro et al. (2009) [19] pointed out that social aspects need to be taken into consideration in power planning and summarized more than 100 indicators of social sustainability of energy projects. Sternberg (2008) [20] argued that the technical, economic, environmental and social dimensions of hydropower co-exist.

There are some established methodologies to measure the energy sustainability in a quantitative manner, e.g. system dynamics [21]; energy return on investment [22]; figure of merit [23] and fuzzy analytic hierarchy process [24]. Multi-criteria decision analysis is a useful approach to aid decision on sustainability energy development priorities [25,26].

The sustainability of hydropower has attracted attention from both governments and the industry. As a result, some guidelines have been developed for sustainable hydropower developments. At Unites States, the Low Impact Hydropower Certification scheme was developed and released by the Low Impact Hydropower Institute (LIHI) to assist reducing the environmental impacts associated with hydropower developments. To be certified as a low impact hydropower, a number of criteria has been developed under 8 groups, i.e. river flows, water quality, fish passage and protection, watershed protection, threatened and endangered, species protection, cultural resource protection, recreation, and facilities recommended for removal [27]. A questionnaire was developed by LIHI to assist the assessment process. These criteria are ecological sustainability oriented and generally refer to legislations such as the Compliance with Resource Agency Recommendations and the Mandatory Fish Passage Prescriptions [27].

In Switzerland, the Green Hydropower Certification scheme was developed by the Swiss Federal Institute of Aquatic Science and Technology (EAWAG). An environmental management matrix is formed to cover a number of criteria to reach the basic standard [28]:

- Environmental dimension: hydrological character, connectivity of river system, solid material and morphology, landscape and biotopes, and biocoenoses.
- Management dimension: minimum flow regulations, hydropeaking, reservoir management, bedload management and power plant design.

Eco-investment to improve local environments is also required to achieve the green hydropower certification [28,29]. Measures to mitigate various environmental issues associated with hydropower developments can be defined in this component (e.g. the percentage of power generation incomes to be contributed towards ecological environment initiatives).

Both the Low Impact Hydropower Certification scheme and the Green Hydropower Certification scheme are heavily environmental sustainability oriented while social aspects and economic aspects are lightly covered. The International Hydropower Association (IHA) released the Sustainability Guidelines for hydropower projects in 2004. This guideline and the subsequent sustainability assessment protocol have defined the criteria of sustainability assessment of hydropower developments (see Table 1). Table 1 indicates the hydropower development needs to pay attention to all three dimensions of sustainability but clearly there are more criteria for environmental and social sustainability compared to economical sustainability.

IHA released the updated Sustainability Assessment Protocol in 2010, suggesting an integrative approach to assess the sustainability of hydropower developments. IHA (2010) [32] encourages the integrative assessment of various aspects of sustainable hydropower (i.e. environmental, social, technical and economic) across various stages of a hydropower project (i.e. early stage, preparation, implementation and operation). For instance, “Downstream Flow Regimes” is a criterion to be assessed at preparation stage, implementation stage and operation stage. Waste management is a key criterion of environmental sustainability however poor waste management performance may have significant social impacts as well. The IHA Sustainability Assessment Protocol showed more focuses on social aspects of sustainable hydropower compared to the Low Impact Hydropower Certification scheme and the Green Hydropower Certification scheme. For example, the social issues are risks will be assessed

Table 2
Example quantifiable indicators for sustainable hydropower.
Sources: [33–36].

Sources	Example indicators
Larson and Larson (2007)	Ratio of the installed capacity to the reservoir area: kW/Ha; ratio of the power generation to the land used by the reservoir: MW h/yr/Ha; ratio of the estimated resettlement cost to the power generation: $/MW h/yr
Carrera and Mack (2010)	Number of residents feeling highly affected by noise caused by power production; percentage of population perceiving esthetic impairment of the landscape
Onat and Bayar (2010)	Unit energy cost ($/kW h); CO_2 emissions (g/kW h); fresh water consumption (kg/kW h), land use (km^2/GW)
Begić and Afgan (2007)	Resource indicator (e.g. fuel indicator and insulation indicator): kg/kWh; Environmental indicator (e.g. CO_2 and NOx indicator): kg/kW h; Economic indicator (e.g. energy cost indicator): $/kW h; Social indicator (e.g. job indicator): h/kW h

and managed at all four stages of the project. Other social related topics include: communities and livelihoods affected by the hydropower development, resettlement, indigenous peoples and public health. In addition, IHA encourages stakeholder engagement during the assessment process, e.g. communication and consultation with public during preparation, implementation and operation stages [32]. Some scholars proposed detailed indicators to allow quantification of sustainable performance of hydropower projects. Some of these quantifiable indicators are shown in Table 2.

3. Research methodology

In order to achieve the research objectives, a case study approach is adopted. As the largest scale hydropower project over the world, the TGP made for an ideal case study. As Yin pointed out, the exploratory nature of case study makes it particularly useful to answer the "Why?" and "How?" questions [37].

Eight project participants were interviewed. They were from the key participating parties namely: the Governmental agency, the client (the Three Gorges Corporation), the contractor and the supervision engineer. They were chosen because (1) they had significant involvement with the project; (2) they were available when this research was conducted; and (3) the multi-source of information improves the reliability of the research.

They were asked to comment on their experience with the sustainable management practice on the project. Specifically, they were asked about the benefits and the issues associated with this project.

After the interview process, some project documents were evaluated in order to confirm the statements made by the interviewees. These documents included:

- Tendering documents.
- Annual environmental management reports.
- Corporation newsletter.
- Other corporation documents.

Content analysis was conducted to highlight the emerging themes from interview notes and project documents. The research findings are reported in the following sections.

4. The three Gorges project—a case study

4.1. Background of the project

The TGP is one of the biggest hydropower-complex projects over the world. The dam is located in the area of the Xilingxia Gorge, which controls a drainage area of 1 million km^2, with an average annual runoff of 451 billion m^3. The TGP consisted of the reservoir, dam, power plant and navigation infrastructures. The dam is 2309 m long and 185 m high that creates a reservoir with 29.3 billion m^3 of capacity. There are 32 turbines that generate as much electricity as 22.4 GW, contributing to one-ninth of China's total output. The navigation infrastructures include double-way and five-step ship lock and a single-way and one-step vertical ship lift (under construction) with capacity to accommodate 10,000 ton fleets and 3000 ton fleets respectively. The amount of concrete utilized in this mega project is 26.43 million m^3.

The project commenced in 1993 and was officially completed in 2009, one year ahead of schedule. The total cost was 180 billion RMB (US 25 billion), which was 20 billion less of the original budget. A high quality standard was maintained where the "Zero Quality-related accident, Zero Safety-related accident" goals are achieved [38].

4.2. Sustainable development practice of the project

The State Council (the central government of China) and the Three Gorges Corporation have recognized that the TGP is a complex system and therefore needs to be managed properly. The sustainability issues are managed from a triple bottom approach (i.e. environmental, social and economical), a life cycle perspective (i.e. conception, design, construction and operation) and a system perspective (i.e. reservoir, dam, power plant, transmission, the location of the project and surrounding areas).

4.2.1. Conception stage

The environmental issues have been considered from the very beginning of the project. At the conception stage, the environmental impacts evaluation was undertaken. The criteria are listed in Table 3.

These criteria generally match the guideline provided by the International Hydropower Agency. The environmental impacts evaluation is conducted according to the Law of the People's Republic of China on Evaluation of Environmental Effects and Regulations on the Administration of Construction Project Environmental Protection in order to minimize the negative impacts on the environment. The State Council coordinated all relevant parties to ensure a number of plans were designed to achieve these sustainability measures. These plans include: initial design of the TGP (Environmental protection part), the implementation plan of the environmental protection in the construction sites of the TGP, the ecological and environmental protection plan of the resettlement areas of the TGP, ecological and environmental monitoring plan for the TGP, and cultural relic protection plan for submerged areas and resettlement areas of the TGP. This environmental evaluation process and associated research are ongoing.

Table 3
Criteria of environmental impacts evaluation of the TGP.
Source: [39].

Categories	Main indicators
Local climate	Temperature, wind, rainfall, fog
Water quality	Diffusibility, biochemical oxygen demand load, land submergence and water quality, sedimentation and water quality, nutrient substance, water quality underneath of the dam
Water temperature	Temperature in reservoir and temperature underneath of the dam
Environmental geology	Induced earthquake, stability of reservoir banks, reservoir leakage
Terrestrial plants and vegetation	Species and rare species, forest and vegetation, resource plants and economic forest
Terrestrial animal	Rare animal, animal population
Aquatic organisms	Spawning ground, fingerling variation, fish resources, rare aquatic animal,
Sedimentation	Reservoir, downstream river channel
Waterlogging and Soil Gleyization	Dongting Lake, Boyang Lake, Sihu areas
Estuary ecological environment	Runoff variation, salinity intrusion, soil salinization, sediment accumulation and erosion accumulation, estuary and offshore fishery
Reservoir inundation and migration	Land submergence, environmental capacity of migration, resettlement plan
Population health	Hygiene, sanitary and health care system, infectious diseases
Natural landscape	Natural landscape
Historic landmarks and sites	Heritage buildings, ancient cultural sites
Construction	Water quality, atmosphere, noise, landscape conservancy
Flooding control	Submergence of cultivated land, guarantee for production and daily living, infectious diseases, life and property loss
Electricity production	Air pollution, solid waste, thermal pollution
Navigation	Marine losses, pressure on the land traffic
Public concern	

4.2.2. Design and construction stage

In order to satisfy the requirements in the TGP environmental impact report and its approval comments, each of the Project's relevant parties made their respective environmental protection plans in the initial stage of the Project that were approved by relevant state authorities. These plans include the Environmental protection of the TGP Preliminary Design, the Environmental protection Plan for the Construction Site of the TGP, the Ecological Environmental Protection Plan for the Emigrant Settlement Zone of the TGP, the Implementation Plan for Ecological Environment Monitoring System of the TGP, Cultural Relics Protection Plan for the Submerged and Relocated Areas of the TGP, the Water Pollution Eradication Plan for the Upper Reaches of the Yangtze River, the Environmental Protection Implementation Plan for Emigrants from the TGP Site and the Environmental Protection and Ecological Construction Plan of the TGP. In 2001, the State Council successively approved the "*Plan for the Water Pollution Prevention on the Three-gorge Project Site and the Upper Reaches of the Yangtze*" and "*Plan for Prevention of Geological Disaster within the Three Gorges Site*". Meanwhile, specialized environmental supervision and water & soil conservancy supervision are adopted to supervise the environmental protection works.

A number of measures were taken to control and deal with the noise, solid waste and waste water properly. The Chinese Government invested RMB 39.2 billion for water pollution prevention and control in the Three Gorges Reservoir and its upstream from 2002 to 2010, as specified in *The Water Pollution Treatment Planning at the Three Gorges Reservoir and its Upstream*. Twenty eight sewage water treatment plants and 20 garbage treatment plants were built to treat solid waste and waste water properly. Meanwhile, 1959 enterprises located in the submerged areas were closed due to a series of issues such as serious pollution, out-of-date technology and energy intensity (1012 planned to be closed) in order to protect the ecological environment of the reservoir area.

The preventive projects for 159 geological disasters located below the water level of 135 m for the Phase II project of the TGP were completed in May 2003. The Phase III Protective projects are currently under construction. In recent years, the central government has invested about RMB 1.2 billion in the control and protective works of about 58,000 km^2 of land that suffers from water and soil erosions.

By the September of 2009, the Government invested more than RMB 71 billion for the resettlement of residents in the Three Gorges Reservoir areas. This includes the construction of housing, roads and other infrastructure.

4.2.3. Operating stage

An environment friendly warranty system that adapts to the TGP operation and management was established, and the ecological and environmental monitoring systems have been strengthened. The environmental risks of the project operation have been studied, and some key environment-friendly technologies have been researched and implemented. The main key technologies under study include: (1) trend, impact mechanism, forecast technology and control technology of eutrophication in the branches and reservoir bays; (2) variability of ecological environment, land utilization and ecological restoration of the water level change regions of the TGP reservoir; (3) pollution features and control technology of the non-point sources, sewage from small towns and solid wastes; (4) environmental capacity for aquatic breeding, breeding modes and pollution control technology in the reservoir; (5) key technology for water quality early-warning, water quality guarantee and water environment management in the reservoir; and (6) study on the impact mechanisms on biological species caused by hydrological changes [40].

In order to regulate and strengthen the ecological environmental protection, a well-established monitoring and management system has been compiled to facilitate the proper execution of various plans and policies for the ecological and environmental protection of the TGP. This system consisted of 1 central station, 11 main stations, 5 experimental laboratory stations, and 58 basic stations. A number of authorities are involved, e.g. water resources, environmental protection, agriculture, forestry, meteorology, hygiene, transportation, land resources, earthquake and China Academy of Sciences. The waste water discharged from the

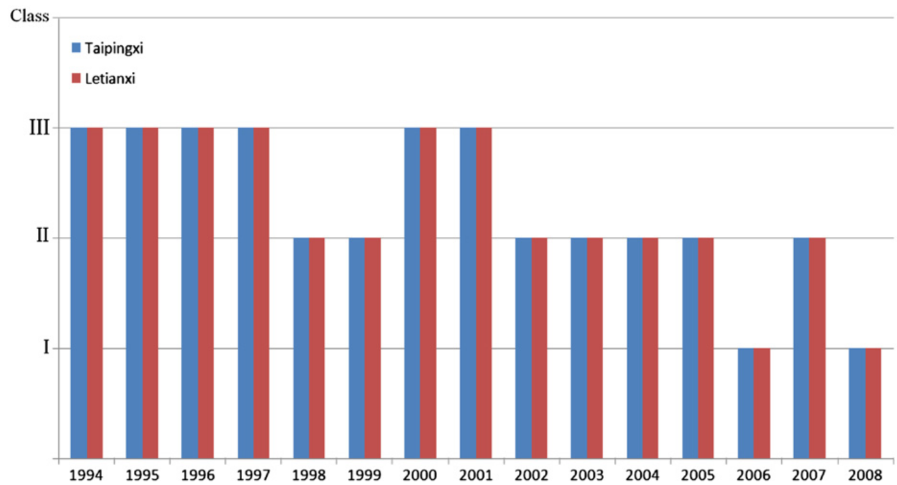

Fig. 2. Water quality of the TGP Reservoir region from 1994 to 2008. Notes: Taipingxi: the section on the front of dam; Letianxi: the section behind the dam. *Source*: [39].

operation of the power plant is set to satisfy the Integrated Wastewater Discharge Standard (GB8978-1996).

Fig. 2 shows that the water quality of the Three Gorges reservoir region from 1994 to 2008. As shown in Fig. 2, the water quality of the region has satisfied the Class II standard since 2002. The water quality after the commissioning of the TGP in 2003 was better than Class III of the Environmental Quality Standards for Surface Water [41]. According to the report released by the Ministry of the Environment Protection (MEP), the water quality of the main stream of Yangtze River and its tributaries is slightly poorer in 2008. MEP asserted that it is mainly due to the major flooding during the autumn season [42].

Natural reserves for terrestrial and aquatic species have been established, e.g. the Hekou Chinese Sturgeon and Paddlefish Parrs Protection Zone, and the Gezhouba Chinese Sturgeon Protection Zone, etc. 30 rare plants and 73 major plants have also been relocated for protection. Continuous efforts have been made on the artificial breeding of Chinese sturgeons to release them into the nature. Great efforts have been made to protect the cultural relics within the project site, including 365 ground cultural relics and 669 underground cultural relics. Some heritage sites are relocated and opened to the public.

The water saving and energy output efficiency and environmental friendly regulation model is adopted during the operating stage to achieve the ecological and environmental benefits of the Project. Ongoing research is conducted to investigate the negative impacts derived from the operation and the measures to mitigate these impacts.

In addition, the environmental protection annual report is released every year to announce the achievements on the environmental sustainability management. Annual report on water and soil conservation in the construction areas of TGP and annual report on the ecological and environmental issues in the construction areas of TGP are made available to the public regularly. Similarly the TGP Ecological and Environmental Bulletin is released annually.

4.3. Sustainability performance

4.3.1. Environmental

According to the environmental auditing: (1) the water quality is better than the Class II standard; (2) the average SO_2 and NO_2 satisfied the Class I standard defined in the ambient air quality standard (GB 3095-1996); (3) Total suspended particulates (TSP) satisfied the Class II standard defined in the Ambient air quality standard (GB 3095-1996); (4) the average ambient noise levels are 56.1dB(A) and 51.0dB(A) at daytime and nighttime respectively.

By the end of October 2009, the Three Gorges power plant has generated 364.4 billion kW h, which is equivalent to 137 million tons of standard coal equivalent. Accordingly, 312 million tons of CO_2, 3.7 million tons of SO_2 and 1.6 million tons of NO_x were reduced from this project.

In 2008, rare species fishes, such as 129,300 Chinese Sturgeon, 2000 Yangtze sturgeon and 418,600 Chinese sucker were released to the Yangtze River. National natural reserves (total river area of 33174.2 Ha) have been established to protect rare species animals and fishes.

4.3.2. Social

The major function of the TGP is the flooding control. The major flood disasters in 1931, 1935, 1954 and 1998 caused a number of casualties. The completion of the Project improves the flooding control capacity from once in ten years to once in a century. It reduced the flood peak of 15,000 m^3/s, which alleviated the flood control pressure of the downstream of the Yangtze River. The Project plays a key role to protect 15 million people living in the middle and downstream of the Yangtze River. During the dry season of year 2009, the Project recharge 12.73 billion m^3 water to the downstream of the river to satisfy the demands from the navigation, manufacturing and living.

The navigation benefit is enormous. In 2009, the freight volume throughout the Three Gorges Water Conservancy Complex reached 74.26 million tonnes, which increased 8.5% from last year. Yichang, the location of the TGP, becomes the logistic center which promotes the sustainable social and economical development of the Yangtze basin. In addition, the navigation cost is cut down to 1/3 and the navigation energy consumption is cut down to 46%.

45% of the project budget is used for resettlement. Apart from the housing development, a large number of infrastructures have been built in the resettled areas. These include: 2 major roads, 2 wharfs, 10 hydropower plants, 42 pumping stations, 37,700 m transmission and transformation lines, 200,000 m telecommunication lines and 581,000 m radio broadcasting and television broadcasting lines in 2007. These infrastructures improve the living conditions of the migrants. Each migrant will receive compensation in next 20 years which is drawn from the electricity tariff. RMB 350 million were invested on the protection of

cultural heritage and cultural relics. Similarly, stand-alone corporate social responsibility report is released annually since 2010.

4.3.3. Economical

Year 2009 witnessed all 26 generating units (the rest six units are for the underground power plant) for the first time to reach the whole factory rated output of 18.2 million kilowatts during the flood season. 79.853 billion kW h electricity was produced throughout the year which counts for 2.57% of the total electricity production across the nation. The electricity generated was mainly transmitted to the central China, Eastern China and Guangdong province, which has contributed towards the economy growth in those regions. The interconnection to the Central China Grid, East China Grid and the South China Grid helps to achieve the peak load shifting benefits between regions, compensation regulation benefits amongst the hydropower plants cluster, and the benefits of exchanging capacity between the hydropower plants and coal-fired plants. For instance, 3–4 million kW h peak load shifting benefits are achieved by interconnecting to the Central China Grid and the East China Grid.

The TGP also contributes towards the rapid economic development of the reservoir area. By the end of year 2007, the GDP per capita of the Three Gorges reservoir area reached RMB 15,100, which is 9.2 times of year 1993. The living condition has improved significantly.

The construction of the project has provided hundreds and thousands of employment opportunities in the local industry. In addition, the tourism industry in the local area develops very quickly which also provides employment opportunities. According to the planning, the tourism industry income will reach RMB 100–120 billion which creates 180,000 new positions by the end of year 2010 [43].

4.4. Factors contributing towards better sustainability performance

During interviews, each interviewee was asked to nominate factors that help to achieve a higher level of sustainability performance of future hydropower developments. These factors are described as below.

4.4.1. Coordination of the central government

Considering the scale, complexity and significance of hydropower project, it is essential for the State Council to coordinate various parties, such as the Three Gorges Corporation, local governments and relevant central government agencies in the Three Gorges Project. The rights and responsibilities of each party should be clearly defined from the beginning.

4.4.2. Consider the sustainability measures from the very beginning

Interviewees recommend to referring to the IHA guidelines as the starting point of establishing an assessment framework particularly for the project. In addition, the ecological and social issues should be given higher priority in all stages of the project, i.e. planning, surveying, design, construction, operating management and maintenance, and retirement treatment so that a win-win (i.e. resource development and ecological protection and social development) solution can be achieved.

4.4.3. International collaboration

According to interviewees, the inputs (technical advice and management expertise) from the foreign experts play an important role to achieve higher sustainability performance in hydropower developments. The collaboration with the International Hydropower Association and the Nature Conservancy helped to pass on the advanced sustainability management skills and expertise to the TGP, according to interviewees.

4.4.4. R&D investment

Interviewees pointed out that it is imperative to invest on R&D to minimize the negative ecological and environmental impacts. The Three Gorges Corporation has established strategic collaboration relationship with various Universities and research institutes to commission studies on key issues associated with the Project such as ecological and environmental protection technologies during the hydropower developments.

4.4.5. Trade-off between objectives

It is worth noting that interviewees commented that the objectives of the hydropower development need to be balanced properly. In China, a hydropower development is normally a Water Conservancy Complex as well. The priority of the complex is the social and environmental benefits. Therefore, economic benefits will be sacrificed for the social and environmental benefits in some circumstances.

4.4.6. System approach

Interviewees also emphasized that hydropower engineering project like the TGP is a complex system which consisted of a number of components. The project also affects the community from various aspects. Therefore, the impacts of the project on the community should be measured comprehensively whereas taking all relevant activities into account simultaneously.

4.4.7. Rolling development of hydropower resources

The Three Gorges Corporation is authorized to be responsible for four cascade hydropower plants, i.e., Xiluodu, Xiangjiaba, Baihetan, Wudongde, on the Jinsha River, a part of upstream of the Yangtze River. The total installed capacity of these four power plants will be 38,000 MW, twice of that of the TGP. According to interviewees, this helps to coordinate the management of flood control, power generation, sediment ejection, and ecological issues across the whole river system. Without this coordination, the hydropower resource development will be disordered, full of disputes and waste.

4.4.8. Ongoing monitoring

Interviewees emphasized that the sustainability management in hydropower projects is an ongoing process. They suggested that the sustainability issues should be audited regularly (e.g. every 3–5 years) to investigate whether or not the regulation is appropriate, whether or not the river channel has been altered significantly, whether or not the river stops flowing due to the development. The operation of the Complex should be adjusted accordingly.

4.4.9. The role of NGOs

Interviewees pinpointed that NGOs play a key role in the decision making process of the TGP. NGOs have participated in the investigation and demonstration of a number of issues in the Three Gorges Project such as migration and water supply. The scrutiny from both national and international organizations motivates more efforts to responsible hydropower development.

4.4.10. Strategic human resource management

Interviewees acknowledged the importance of developing human resources strategically in the Three Gorges Project. According to interviewees, the Three Gorges project helps to develop the human resources, e.g. managing complex and large scale projects sustainably. In fact, project management skill base

is developed very well so that some project management personnel are assigned to manage both internal and external complex projects such as the National Aquatic Center (Water Cube) and other renewable energy developments undertaken by the Three Gorges Corporation. Interviewees pointed out that efforts should be made in any renewable project to develop employees' skills and knowledge particularly on sustainable development.

5. Conclusions

Hydropower projects are generally very large scale and complex. As one type of renewable energy resources, the hydropower development brings in a number of benefits such as GHG emission reduction and providing the flexibility of electricity production and supply. However the sustainability issues associated with hydropower developments should not be neglected. This study adopted a case study approach to investigate how the sustainability issues were handled in the TGP. This study adopted the sustainability assessment framework provided by IHA to satisfy the research purpose. The results show that the TGP does accommodate various aspects of sustainability according to the guideline released by IHA to a certain degree. As a result, the Three Gorges Project has delivered considerable benefits, particularly the flood control and navigation. The strategic sustainable development approach has been adopted by the Three Gorges Corporation in other energy projects.

The TGP is not issue-free. Resettlement issues and environmental issues are mostly cited by the criticisms. However, it is not deniable that the Chinese Government and the Three Gorges Corporation has made efforts to mitigate these negative impacts. Similarly the interviews identified some critical factors for achieving a higher level of sustainability performance in future hydropower projects. These results provide a useful reference for the sustainability management in future hydropower developments in China.

It is beyond the scope of this paper to quantify the sustainability performance of hydropower projects. There are an increasing number of studies that proposed a comprehensive framework to quantify the sustainability performance of hydropower and other renewable energy projects. Future research opportunities exist to adapt these frameworks to further investigate how hydropower developments perform sustainably.

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